REMARKS

The following remarks refer to the Examiner's comments on the noted page and line number of the Office Action letter dated 4-18-01. His comments are quoted here for convenience. Where Remarks refer to pages in the Specification, the reference is made to the "Marked-up Version".

Quoting p. 2, beginning line 20:

"The Specification is objected to under 35 U.S.C. 112, first paragraph, as failing to provide as adequate written description of the invention and as failing to adequately teach how to make and/or use the invention i.e. failing to provide an enabling disclosure."

Remark 1:

The specification has been revised to clarify all points made by the Examiner. Descriptive material and distinctions between the present invention and prior art have been added in the appropriate areas of the Specification. Several examples are noted here: (1) the "Host Metal Selection" section on page 10 is expanded; (2) the enabling process is clarified in Specification sections "Brief Summary of the Invention" on page 4 and "How the Reactor Works" on page 9; (3) the operating range of the reactor in terms of deuterium chemical potential, temperature and pressure is now shown in the text and in the Drawings, Figure 7,; and (4) in the claims, the methods for enabling and controlling the fusion reaction are now claimed.

Quoting p. 3, beginning line 1:

"There is no reputable evidence of record to support any allegations or claims that the invention involves nuclear fusion nor, that any allegations or claims of "excess heat" are valid and reproducible,....."

Remark 2:

The Examiner's statements are based on newspaper articles, interviews and technical reports that were published many years ago. While these articles and reports are of historical interest, they do not reflect the current status of tests that

demonstrate that deuterium fusion and the resulting "excess heat" is indeed taking place when the 'F&P effect' is initiated and sustained in the deuterium-palladium system.

Of the many successful cold fusion experiments that have been conducted worldwide in the past 10 years (see **Enclosures 2 & 3**), four such experiments of particular significance have been replicated in the laboratories of the Stanford Research Institute, International, (SRI) in Menlo Park, CA.

The four original experiments were conducted by: (1) Dr. Arata, in Japan using a combination of electrolytic and gas loading of the deuterium into the palladium host; (2) Dr. Miles, in California using electrolytic loading; (3) Dr. Case, in Connecticut, using pure gas loading in the presence of carbon; and (4) Dr. McKubre, in California, using electrolytic loading. The original experiments clearly produced excess heat as well as the expected helium byproducts of the fusion reaction. (See references cited in Enclosure 1.)

The replication effort at SRI was conducted with remarkable attention paid to accuracy of heat measurements and to laboratory techniques that preclude any possibility of contamination from external sources. The presence of helium 4, helium 3 and tritium was not only detected but measured and correlated to the excess heat produced. This meticulous work, under the direction of Dr. Michael McKubre with participation by Dr. Peter Hagelstein of MIT, was made possible by a ten-year series of improvements in both laboratory techniques and advancements in mass spectrography demanded by a skeptical scientific community. It is the opinion of the applicants that, as the process of critical review by the scientific community progresses, one can no longer dismiss the reality of deuterium fusion and the production of heat in the deuterium-palladium system.

The results of this experimental replication work were presented at ICCF-8, the 8th International Conference on Cold Fusion held in Italy during the early part of the year 2000 and are just now published in the proceedings of that conference. A copy of the paper prepared and presented by Dr. Michael McKubre, et al, is included as **Enclosure 1** and is incorporated into the Specification as **Reference 6**.

This noted group of experiments and their replication at SRI constitutes reputable evidence that nuclear fusion and excess heat can be induced in the

deuterium-palladium system and that the effect is reproducible.

(Note: Remark #3 is not used.)

Quoting p. 3, beginning line 1:

"There is no reputable evidence ..... , **nor that the invention as disclosed is capable of operating as indicated and capable of providing a useful output.**"

In responce to the examiner's comment quoted above, **Remarks 4 thru 8** must be considered as a group:

Remark 4: Useful output

For the output of any deuterium-palladium system to be considered useful for commercial applications, the output power density must be in excess of 1000 watts per cubic centimeter of palladium for the heat produced to be cost competitive with that produced by fossil fuels due to the high cost of the host metal. Further, the reactor must not rely on the continuous application of expensive energy input to achieve an 'excess'. This definition of 'useful power' precludes the use of any deuterium loading method other than 'gas loading'.

The invention setforth herein is a pure gas loaded reactor. The design of the reactor and the operating procedures set forth in the Specification will produce the necessary conditions for achieving power densities in the commercially useful range.

Remark 5: Experimental evidence of high density heat.

Experimental evidence of high power densities being produced by the deuterium-palladium system is found in some of the early work performed by Fleischmann & Pons (F&P). While the vast majority of their work was performed using a carefully controlled electrolytic process, they experienced extremely high power densities when a cell electrolyzing a 1 cubic centimeter sample of palladium accidentally ran dry due to electrolyte boiloff. This stopped the electrolytic process and the Pd cathode began to operate as a 'gas loaded' reactor.

When immersed in the liquid electrolyte, the heat transfer coefficient from the Pd

cube to the liquid was very high. When the electrolyte 'boiled off', the electrolytic process stopped and the heat transfer coefficient from the Pd to the surrounding air dropped to a very low value. The relatively small amount of fusion heat being generated in the sample (estimated to be about 100 watts/cc at 100°C) was greater than that which could be transferred to the surrounding atmosphere because of the reduced heat transfer coefficient. As a result, the palladium experienced positive temperature feedback. The temperature began to rise and the reaction rate began to increase rapidly. The 1 cc sample of Pd reached its melting temperature of 1554°C. A portion of the Pd cube actually vaporized (at 2963°C) before the episode eventually came to an end. The lengthy overnight episode ended when the last of the ionic deuterium in the Pd sample was diffused out to the lab atmosphere and the reacting deuterium was converted to the helium and tritium byproducts of the fusion reaction. The melting and vaporizing of the palladium is clear evidence of a very high power density. The large hole in the laboratory bench and the large depression in the concrete floor due to vaporization of those materials is additional evidence of extremely high power densities. (See **Enclosures 4 & 7.**) *Based on even the most conservative estimates of the energy that must have come from that 1 cc of palladium, there can be little doubt that a nuclear 'event' took place in the F&P lab at very high temperatures producing commercially useful levels of heat.*

Following this near disaster, F&P conducted a number of controlled 'boil dry' experiments using Pd rod instead of a cube. These experiments produced power densities in the range of 3.6 kw/cc of Pd at temperatures estimated to be in the 500 to 600°C range. No effort was ever made by F&P to maintain a deuterium atmosphere at the surface of the palladium after boiling dry, so the high density fusion reaction came to an end in due time.

The experimental evidence developed by F&P is now incorporated into the amended Specification in Figure 9 of the "Drawings" section. This Figure 9 also shows other data at temperatures above room temperature showing the strong influence of higher temperatures on the power density.

F&P did not pursue gas loading as a method for producing high density heat from deuterium fusion because they, as well as all other skilled artisans, believed that the key to enabling the fusion process was to achieve very high deuterium

concentrations in the palladium metal. While they correctly envisioned no practical way to achieve high D/Pd loading ratios by gas loading methods due to the extreme pressures required *at low temperatures* (100,000 atmospheres and higher), they failed to recognize that the D/Pd concentrations in the 'boiled dry' cathodes were indeed quite low when the palladium was producing the highest power densities. As were all others skilled in the art of electrolysis, they were victimized by the kind of data shown in Figure 2 of **Enclosure 5** and the 'logical' conclusions one might draw.

The invention disclosed herein relies on reproducing and maintaining the very high 'system free energy states' at the high temperatures and modest equivalent pressures that were present when the 'boiled dry' reactors were producing power densities in the commercially viable range.

Remarks 6: Operating zone for high density heat.

To determine if it is practical to design a gas loaded reactor capable of producing high power densities, it is necessary to determine the D chemical potentials produced by electrolysis at typical operating temperatures when producing low density excess heat. The technique for making these estimates is described in **Enclosure 10** using the TCP Equilibrium Diagram. The results are presented in Figure (5) , **Enclosure 5**, "This Invention vs Prior Art". At typical electrolyte temperatures, on the left side of the chart, the equivalent free energy states (expressed as the D Gas Chemical Potential) produced by electrolysis range below 15 kJ/mol. (Higher values are not possible due to the temperature limit on the electrolyte and due to the vagaries of the electrolytic process.) It is known that the presence of an electric field does work on the dissolved deuterium and may have the effect of producing an additional increment to the deuterium chemical potential; this increment has been estimated to be less than 5 kJ/mol. To produce substantially higher density power by gas loading, it is necessary to produce D gas chemical potentials substantially higher than those associated with the low power densities of the electrolytic process.

On the right side of Figure 4, **Enclosure 5**, the broad operating zone for this present invention is noted between 400°C and more than 1400°C and pressures from more than 4000 atmospheres to 25 atmospheres or so (noting that pressures must be

reduced at the higher temperatures due to reduced strength properties of typical reactor pressure vessel materials at temperatures above 500°C to 700°C).

The reactor design disclosed herein is capable of producing D gas chemical potentials twice that produced by any known prior art; gas loading or electrolysis.

Remark 7: A change of thermodynamic state is the key to operability.

Thermodynamics teaches us that a 'change of state' will occur in a system if and when a lower free energy can be achieved. This is analogous to the solid-liquid-vapor state changes for most materials when the required combination of temperature and pressure are produced. In solid state physics, when substances are dissolved in metals (such as hydrogen in palladium) the 'free' electrons change to a delocalized state or to a multiplicity of smaller wave functions having the symmetry of the metal lattice (sometimes referred to as the 'Fermi sea', or the 'Fermi gas').

While the exact nature of the deuterium change of state is not yet explained to the satisfaction of the technical community, the reality of deuterium fusion in the palladium lattice (**Remark 2**) leads to the conclusion that a state change does indeed take place to enable the reaction and to be consistent with thermodynamics. In **Enclosure 8**, such a change of state is described in layman's terms as taken from one of today's prominent theories.

Remark 8: Operability

Determination of the system free energy state at the threshold of the necessary 'change of state', for the selected host material, and operation of the system at free energy states higher than the threshold are key to making this invention operable over the broad range of operating conditions now noted in Figure 7 of the revised Specification.

Quoting p. 3, beginning line 5:

> **"The invention (see for example pages 1+ of the specification) is considered as being based on the "cold fusion" concept setforth by Fleischmann and Pons (hereafter F and P) (see the 3/24/89 article by D. Braaten). This concept relies on the incorporation of deuterium into a metal lattice. While F and P relied on electrolysis of heavy water to incorporate deuterium into the metal lattice, it was also known that as a variation, the deuterium could be incorporated into the metal lattice by bringing the metal in**

contact with deuterium gas.

"Thus it is clear that applicant's invention is just a variation of the cold fusion concept set forth by F and P."

Remark 9:

As observed by the examiner, the invention disclosed herein incorporates deuterium into the metal lattice by bringing it in contact with the surface of the metal under specific conditions. When deuterium gas and the host metal are brought together inside of a pressure vessel, equilibrium conditions between the deuterium gas subsystem and the deuterium-metal subsystem are noted on the D-Pd TCP Equilibrium Diagram now shown in Figure 8, of the revised Specification. The definition of equilibrium in this gas-metal system is that the chemical potential of the deuterium gas in the gas sub-system is equal to the chemical potential of the dissolved deuterium in the metal sub-system. The data incorporated in the Equilibrium Diagram are a composite of fragmentary data presented in the literature over a period of more than 100 years. (See TN-1.0 in **Enclosure 9**.)

The present inventors make no claim that bringing the deuterium gas in contact with the surface of the metal is a unique method of incorporating deuterium in the metal. Further, they make no claim as to the invention of the "cold fusion concept".

What is claimed is the system and methods for enabling and accelerating the fusion reaction making the present invention easily distinguished from all prior art.

Quoting p. 3, beginning line 13:

"However, as set forth more fully below, this "cold fusion" is still no more that just an unproven concept.

"Subsequent to the announcement of the cold fusion concept by F and P, many laboratories have attempted to confirm the results of F and P.

"The results of these attempts at confirmation were primarily negative and even of the few initial positive results, these were generally retracted or shown to be in error by subsequent experimenters (see for example, the article by Stipp in the Wall Street Journal and the article by Browne in the New York Times (particularly page A22)"

Remark 10:

While **Browne** touts the sensitive equipment used by Cal Tech, their work later turned out to be less than totally professional.

Since the noted articles by **Stipp** and **Browne** were published, numerous

experiments have been conducted at various laboratories around the world that clearly show excess heat plus the production of helium byproducts. Four of these critical experiments have been replicated recently by a reputable and prestigious laboratory (SRI) according to the normal protocol of scientific discovery. (See **Remarks 2** above, **Reference 6** in the revised Specification and in **Enclosure 1**.)

The articles cited in the Office Action are of historical interest only. We can no longer considered 'Cold fusion' just an unproven concept.

Quoting p. 4, beginning line 1:

> **"The general consensus by those skilled in the art and working at these various laboratories is that the assertions by F and P were based on experimental errors, (e.g. see The New York Times article by Browne, Kreysa et al, Lewis et al, Hilts, Horanyi, Ohashi et al, MisKelly et al, and Chapline).**

Remark 10a:

The **Browne** article reports the scorn placed on F&P by many of their peers 'skilled in the art'. It was discovered later by review of their data, that some of those who scorned the loudest had themselves conducted terribly flawed attempts at replicating the F&P effect; some actually having produced excess heat and didn't recognize it. Today, the most careful and better equipped labs in the U.S., Japan and Italy have produced excess heat along with the expected helium byproducts.

Remark 10b:

The reports by **Kreysa, et al, Lewis, et al, Hilts, Horanyi, Ohashi, et al, and MisKelly, et al**, cite their failures to replicate F&P's work and concluded that F&P had to have made experimental errors. Such reports are of historical interest since the reality of deuterium fusion in palladium is now established. It would, however, open up the question as to who actually failed to create the necessary critical enabling conditions or who may have actually made experimental errors.

Remark 10c:

The **Chapline** article speculates that the deuterium gas pressures required to produce a "pyconuclear" reaction would be on the order of 10 million atmospheres. The applicant's invention produces free energy states at elevated temperatures which

have equivalent room temperature pressures in this same range and higher.

Chapline also notes that apparently the dissolved deuterium behaves in a manner similar to that of the free electrons in their delocalized state. He sees this as amusing rather than a real possibility. Doctors Talbot and Scott Chubb who have developed one of the leading solid state deuterium fusion theories based on the concept of the dissolved deuterium becoming delocalized, just as the free electrons do, to nullify the Coulomb repulsion forces (see **Enclosure 8**). (The Chubbs' theory is one that fits the experimental data and is consistent with the teachings of thermodynamics and solid state physics.)

Chapline makes no mention of attempts on his own to replicate the F&P work at the Livermore National Laboratories.

As to the reality of deuterium fusion in the D-Pd system in today's light, please revisit **Remark 2** and **Enclosure 1**.)

Quoting p. 4, beginning line 5:

> **"It is also the general consensus by those skilled in the art and working at these various laboratories that there is no reputable evidence of neutron, gamma ray, tritium or helium production to support the allegation or claim that nuclear fusion is taking place, nor is there any reputable evidence to support the allegation or claim of excess heat production. See for example (in addition to the above listed references), pages A14 of the 7/13/89 edition of the Washington Post, Cooke, Alber et al,Faller et al, Cribier et al, Hadjas et al,Shani et al, Ziegler et al, Price et al, Schrieder et al, and page A3 of the 3/29/90 edition of the Washington Post."**

Remark 10d:

The **Washington Post article** cites the end of government funding for any "cold fusion" work based on the Energy Research Advisory Board's recommendation. **Cooke's document** is a trip report of a side conversation with Harwell people who had recently experienced failure to replicate F&P's work or the gas loaded Frascatti-type experiments. **Horanyi** argues about the vagaries of electrochemistry and takes issue with F&P statements. **Faller** could not measure gamma rays however he did measure tritium in an amount equal to 1/3 of that reported by F&P. **Cribier** could find none of the expected radiation had fusion taken place. **Hadjas** added to the list of experimenters that failed to measure neutrons in Frascatti-type gas loading

experiments (see **Remark 12**). **Shani** measured neutron bursts but speculated that they may have been triggered by an outside source rather than deuterium fusion. **Ziegler** and **Schrieder** both failed to replicate F&P's work. **Price** failed to measure charged particle emissions from deuterated samples of Pd and Ti. In the cited **Washington Post article, Salamon** and **Price** depreciate F&P in light of their own failure to replicate the latter's work.

None of these articles and reports reflect on the efficacy of this present invention.

Many of those 'skilled in the art' conducted terribly flawed attempts at replicating the F&P effect. An error common to most electrolytic experiments was that no measurements of the actual loading ratio (D/Pd) were made leaving doubt that their failed replication efforts were valid. The SRI labs in Palo Alto found it absolutely necessary to establish this assurance that loading actually took place in every instance and their success record exemplifies their care.

In any case, and in today's light, using advanced testing and measuring techniques, the production of excess heat and the expected helium byproducts has been confirmed. (See **Remark 2** and **Enclosure 1**.)

Quoting p. 4, beginning line 15:

> **"Note that the negative teachings of the gaseous systems of such references as Friedmann et al, Price et al, McCracken et al, and Badurek et al, are particularly pertinent in regard to showing inoperability of applicants gaseous system."**

Remark 11:

The cited report by **Friedmann, et al**, concerns, in part, gas loading experiments using Titanium as the host metal. **Friedmann** followed De Ninno's procedures and went to great lengths to achieve high loading ratios by temperature cycling his Ti and TiFe samples repeatedly from liquid nitrogen temperature to 200 deg C. This procedure is applicable to the process for storing hydrogen in titanium (i.e. packing in the maximum amount of gas by achieving high D/Pd loading ratios) but is well known to have a very destructive effect on the uniformity of the metal's lattice structure. Since the leading solid state fusion theories of today involve coherent action within the lattice structure to nullify the Coulomb repulsion forces (see **Enclosure 8**), the

integrity of the lattice must be preserved to allow the fusion process to be enabled. One would not expect to produce nuclear fusion using the gas loading testing techniques employed by **Friedmann** and De Ninno. It is surprising to the present inventors that De Ninno achieved positive results. (Also see **Remark 26b**.)

Also, the maximum deuterium gas chemical potential (i.e. the measure of the system free energy state) achieved in Friedmann's work was very low (7.7 kJ/mol) and *would not be expected (by the present inventors) to enable the fusion reaction had it been applied to a palladium system.* This failed approach by Friedmann does not reflect on the efficacy of the approach employed in the present invention. The threshold chemical potentials for a gas loaded palladium system are, in most cases, in excess of 20 kJ/mol. (The threshold deuterium gas chemical potentials required to enable a fusion reaction in titanium has not yet been determined by the present inventors.)

Remark 12:

The cited report by **Price, et al**, concerns, in part, gas loading experiments using both titanium and palladium as the host metals. **Price** used a similar temperature cycling technique prior to final loading that **Friedmann** and De Ninno used. The primary difference is that the deuterium gas chemical potential used during the measurement runs was even lower than Friedmann's (<1kJ/mol). (Also see **Remark 26b**.)

Remark 13:

The cited report by **McCracken, et al**, again, is similar to the **Price, Friedmann** and De Ninno works, but excluding palladium as a host metal. Here they produced deuterium gas chemical potentials in the range of <1 kJ/mol to 6.0 kJ/mol which are well below the minimum required to enable the fusion reaction.

Remark 14:

The cited report by **Badurek, et al**, again is similar to the **Price, Friedmann, McCracken** and De Ninno work where titanium was gas loaded and temperature cycled, also citing the pulverization of the outer surface of titanium. The actual

deuterium test pressure is not reported to permit a chemical potential calculation, but it may be assumed that the deuterium gas chemical potentials were in the same very low range as in the other experiments since **Badurek** made no mention of using an ultra high pressure test apparatus.

Remark 15:

Note that the four papers, cited above, report failed attempts to replicate work carried out by the Frascati Group which is covered by European Patent 0394204 by Scaramuzzi, De Ninno, et al. All gaseous experiments aimed at achieving high D/Pd loading ratios are essentially a waste of time, as so aptly reported, because it is not practical to achieve the ultra high pressures needed to produce the threshold free energy state (D chemical potential) at the low temperatures. (See **Enclosure 5**.)

The failed approach noted in the four cited papers and in the Scaramuzzi patent does not reflect on the efficacy of the present invention.

Quoting p. 4, beginning line 15:

> **"Of particular interest is page A3 of the 3/29/90 edition of The Washington Post (which refers to the negative findings of a physicist who tested Pons' own cold fusion apparatus, for nuclear output (for a more complete analysis of said "negative findings", note the article by Salamon et al)). Also of interest in this respect is the Cooke reference which on pages 4 and 5, refers to the attempts at Harwell to obtain "cold fusion" and that Fleischmann (of F and P) had requested help from Harwell in verifying the cold fusion claims. Note that said page 5 also indicates that data was collected in Frascatti-type experiments (i.e. gaseous).**
>
> **"The last paragraph on said page 5 states:**
>
> **"After three months of around-the-clock work at a cost of a half million dollars, the project was terminated on June 15. This program was believed to be on of the most comprehensive worldwide with as many as 30 cells operating at a time and over 100 different experiments performed. The final result of this monumental effort in the words of the official press release was, "In none of these experiments was there <u>any evidence of fusion</u> taking place under electrochemical conditions". It should also be added that there was no evidence of excess heat generated by any of the cells."**

Remark 16:

As noted in **Remark 2,** the search for cold nuclear fusion has persisted to the present time (see **Enclosures 2 & 3**). Since early days covered by the obsolete

articles cited above, critical experiments showing excess heat and nuclear byproducts have since been conducted and replicated as noted in **Enclosure 1**.

The **Cooke et al** reference, page 5, where Harwell also failed to gather positive data on Frascatti type experiments, as well as the F&P type, is as expected by the applicants. (See **Remarks 11, 12, 13 & 14**.)

*Again, the **Cooke** report on the rather extensive **Harwell** effort does not reflect on the efficacy of the approach employed in the present invention.*

Quoting p. 5, beginning line 11:

> **"The applicants specification contains assumptions and speculation as to how and in what manner, his invention will operate. However, applicant has presented no factual evidence to support his assumption and speculation that when Pd metal has deuterium absorbed of adsorbed therein, the deuterium nuclei can be caused to undergo nuclear fusion to produce heat. The disclosed utility is a power producing system responsive to load demands (e.g. see page 12 of the specification). However, there is no reputable description nor enabling disclosure of an operating nuclear fusion system or process which could actually produce such useful amounts of energy."**

Remark 16a:

The reality of the deuterium fusion in a metal lattice took more than a decade to confirm beyond reasonable doubt. The extremely low reaction rates demonstrated in almost all experiments to date has made the effect difficult to detect without extreme care in procedures and without some rather sophisticated equipment. The applicants might well have been among the skeptics except for the few instances of high density heat having been produced as noted in **Remarks 4 & 5** and is incorporated in the revised Specification in Figure 9.

The reality of high density fusion heat is most dramatically described in **Remark 5** and **Enclosure 7**. (Also see Figure 3, **Enclosure 5**.) It is from the referenced experimental data, not from **"assumptions and speculation"**, and with considerable skills in the art of thermodynamics, material sciences and solid state physics that the applicants evolved the present invention along with its operating methods as noted in **Remarks 6, 7 & 8** and in numerous remarks that follow about the methods noted in the Specification to implement the design.

The system for responding to load demands is now noted on page 19 of the

Specification. For a sealed reactor, see page 15 of the revised Specification.

Quoting p. 5, beginning line 19:

> **"There is no adequate description nor enabling disclosure of the minimum concentration of the deuterium in the metallic catalyst (e.g. the D/Pd ratio) that is necessary for the indicated fusion reactions to take place."**

Remark 17.

All prior art is based on achieving the highest possible concentrations (D/Pd) and there being a minimum, or 'threshold' concentration of deuterium in the palladium metal for enabling the fusion reaction. Figure 2 in **Enclosure 5**, "This Invention vs. Prior Art", shows typical data that led investigators to follow the course of seeking high D/Pd concentrations. The prevalence of this belief in the need for high concentrations caused investigators to concentrate on using the lower temperatures, where a high concentration can be achieved. This principle, however, is correct for a constant temperature, but is not generally true over a range of temperatures (see Figure 3 in **Enclosure 5**).

The enabling method for this invention is distinct and is described in the Specification in "How the Reactor Works", page 9. This enabling method is embodied in the detailed operating procedures of the Specification.

The invention disclosed herein sets no minimum D/Pd concentration. The D concentration will be that concentration consistent with the temperature and pressure required for the desired D chemical potential.

Quoting p. 6, beginning line 1:

> **"There is also no adequate description nor enabling disclosure of how and in what manner, the "minimum" concentration of deuterium in the metallic catalyst is initially obtained and then maintained, so as to present an operative device."**

Remark 18:

For the invention disclosed herein, a specific minimum D concentration is not required. (See **Remark 17** above.)

Quoting p. 6, beginning line 4:

"The specification on page 12 lines 12+ states that as the deuterium is depleted (due to undergoing nuclear fusion) the power production rate for a given temperature will decrease and, to compensate, the reactor is operated at gradually higher temperatures over the life of the reactor (the disclosure, however, is insufficient as to how and in what manner such is accomplished)."

Remark 19:

The revised Specification includes a new section entitled "Useful life of the Sealed Reactor", on page 17, to correct the noted deficiency in the old Specification.

"**Quoting p. 6, beginning line 8:**

"Said page 12 of the specification also implies that there is no minimum deuterium concentration in the metal below which nuclear fusion will not occur (the specification is insufficient as to the basis for such)."

Remark 20:

As noted in **Remarks 17**, this invention relies on producing high system free energies, corresponding to high D chemical potentials, to enable and accelerate the fusion reaction. High D chemical potentials are achievable at high temperatures where D/Pd concentrations are low. It is only necessary that *'some'* deuterium be present in the solid. The gas-metal system will remain in equilibrium (saturated) even though the D/Pd ratio is small. As noted in Enclosure 9, at the bottom of Figure 4, Krumbhaar measured some hydrogen in molten palladium at 1600°C in 1910.

Quoting p. 6, beginning line 11:

"The disclosure is insufficient as to the minimum size of vessel 2, the thickness and quantity of host metal, the concentration of deuterium in the host metal, the deuterium gas pressure in the vessel 2, etc., necessary to present an operative embodiment of applicants invention."

Remark 21:

The Specification points out repeatedly that the design of the reactor for a specific application depends on the application requirements. Typically, these requirements are stated as: (1) a specific operating temperature and (2) a necessary heat flux from the heat transfer surface. As an example, for an application requiring

radiant heat from a 'black body' surface, the requirements might be given as 15 watts/cm^2 from a black body surface at 1000°C.

The Specification (page 10) defines the methods for (1) selecting a host metal **(quality)** and (2) measuring its power density over a range of operating chemical potentials at the 1000°C operating temperature. These data provide (using Equation 1, page 10) a range of operating pressures for the selected host metal that will provide reasonable power densities.

Using the required operating temperature and the highest pressure in the range, an engineer will select an appropriate material for the reactor body (page 7 in the Spec) from data sheets provided by suppliers of high temperature metals and alloys. Using the supplier data sheets, the engineer will determine, by stress and strength analysis, an optimum operating **pressure**, inside diameter and wall thickness **(size)** for the reactor body. Using the optimum pressure and the measured power density data for the selected host metal, the engineer can now select the proper **thickness** of host material to install inside the reactor to satisfy the application heat flux requirements.

The Specification provides the methods for selecting the host metal and measuring its heat-producing performance. From these data, the necessary gas pressures are derived. From this point on, it is a 'textbook' approach to pressure vessel design for anyone skilled in the art.

Enclosure 6 summarizes the design approach and shows a typical optimization design analysis including a spread sheet to develop the design envelopes as they relate to temperature, pressure and chemical potential for Carpenter's Pyromet 680 high temperature alloy. The Carpenter data sheet is also included to show typical stress rupture data for using the material at temperatures over about 600°C.

Quoting p. 6, beginning line 15:

> **"The disclosure is insufficient as to how and in what manner, the host metal is 'distributed' inside the reactor vessel (including in 'deposited' form)."**

Remark 22

The Specification is revised to add "Host Metal Installation" which now

describes three candidate methods of installing the host metal.

Quoting p. 7, beginning line 1:

> **"The specification on page 6 lines 18+ states the 'threshold chemical potential of the host material' (and hence the operability of applicants invention), is dependent on various factors including the purity, crystal size and regularity, and the population of flaws, crack, vacancies, distortions and dislocations in the crystal lattice structure of a particular host material.**
>
> **"The disclosure however, is insufficient as to what point (e.g. the size and extent of the populaton of cracks, the requisiste degree of purity (and as to what impurities would be permissible)S, etc.), any of these various factors (or combinations thereof) would prevent operability.**
>
> **"Further in this respect, the disclosure is insufficient and non-enabling as to what effect such parameters as the porosity of the metallic lattice, the degree, type and amounts of impurities in the metallic lattice, etc., have on the ability of the indication nuclear fusion reactions to take place and thus present an operative device."**

Remark 23:

The method for selecting the host metal is expanded in the revised Specification (page 10) to be more explicit that it is the measurement of the threshold chemical potential of a candidate metal in its elected form that permits selection of the best host metal; the best being that metal with a low threshold deuterium chemical potential.

By this screening test method (such techniques being common in todays high tech industries) the variation in the micro-properties of the host metal is summed in the one macro-property, 'threshold deuterium chemical potential'. Some candidate metals may be found to be inoperable and must be rejected. Once this property is measured, there is an associated family of temperature and pressure combinations that may be used in design to produce the threshold conditions.

Quoting p. 7, beginning line 13:

> **"There is no adequate description nor enabling disclosure of the parameters of a specific operative embodiment of the invention, including exact composition (including impurities and amounts therof) of each of the host metal, the filler material and the host metal support (the vessel wall material or that of the hydrogen impervious coating thereon, if such is present), the density of the host metal, the temperature and pressure inside the vessel, the minimum concentration of deuterium in the host metal necessary for the nuclear reactions to take place, the temperature to which the host metal must be heated before nuclear reactions will take place, etc."**

Remark 24:

All of the above items have been covered in previous comments by the Examiner, and answered in previous remarks, except the one about the 'hydrogen impervious coating'. In this instance, beryllium-bronze has been added in the Specification, page 7, line 25, as a candidate impervious material. Anyone skilled in the art of material sciences may choose to select an alternate material for that purpose. Its precise selection is not critical to the operability of the present invention.

Quoting p. 8, beginning line 1:

> **"Applicants invention basically involves placing a hydrogen absorbing metal in a container, causing deuterium to be absorbed into said hydrogen absorbing material, which in turn, result in the deuterium undergoing nuclear fusion reactions.**
>
> **"However, the concept of storing deuerium in a vessel containing a hydrogen absorbing material (including under high pressure and where heat is applied) has been notoriously well known for many years. As examples thereof, resort may be had to Klatt it al (I), McMullen eta al, Carstens et al, and Schirber et al.**
>
> **"However, the systems as disclosed in these four examples were not considered as being reactors wherein nuclear fusion took place.**
>
> **"Indeed, if nuclear fusion did take place in said four examples, thus causing the hydrogen isotopes to be depleted due to burn-up, the systems in said four examples would have been rendered inoperative for their intended and disclosed purposes."**

Remark 25:

Yes, the concept of storing deuterium in a material, using high pressure and heat has been well known for many years.

Klatt et al uses such storage, and utilizes the heat developed as deuterium is introduced into the metal. This exothermic heat is also well known and is called "heat-of-solution" by metallurgists. This is one of several well known heat effects accompanying the entry of deuterium. The others are heat of dissociation, heat of transformation and heat of ionization. None of the four are connnected with excess heat associated with deuterium fusion. They are relatively small, and are transient heats that occur only at the time these three phonomena occur, and must not be confused with the "excess heat". The excess-heat is associated with fusion and can continue for long periods of time. Investigators of excess-heat associated with fusion,

routinely subtract the transient heats observed to calculate the "excess heat".

The maximum chemical potential achieved in **Klatt's** invention, during presence of the transient heats, was on the order of 5kJ/mol when using palladium. There is no reason to expect deuterium fusion to be enabled under the conditions noted for **Klatt's** invention.

McMullen et al also use this well known exothermic heat-of-solution.

Carstens et al utilizes vanadium metal containing a hydrogen isotope to produce high pressure by heating in a constant volume. This is well known in the art, and is not connected to the production of excess heat connected with fusion which is the subject of applicants invention. Further, it is **Carstens** "pump" principle by which 'pressure amplification' is achieved in the 'Sealed Reactor' version of this present invention which uses the inert filler material to control the free-gas-volume of the reactor. (See **Enclosure 11**.)

Also, the **Carstens** apparatus never produced D chemical potentials above 8kJ/mol which was well below that anticipated for enabling a fusion reaction in Pd.

Schirber et al utilized palladium hydride and deuteride to study the effect of hydrogen or deuterium concentration on the superconducting transition temperature of palladium. From the quoted temperatures and pressures (room temperature and 5kbars) **Schirber** produced D chemical potentials of only about 10 kJ/mol; again, too low to enable a fusion reaction by gas loading.

*The **Klatt et al, McMullen et al, Carstens et al and Schirber et al** references cited do not anticipate the present invention nor do they reflect on the efficacy of the present invention.*

There have been many other investigations about the loading of metals with deuterium. The question asked by the examiner is, since all such studies "load" deuterium into a metal, and in some cases the metal was palladium, why didn't they notice the excess heat due to fusion, and the decrease of the effect with the depletion of deuterium. The answer is that it is unlikely that any of them produced the special conditions (sufficiently high chemical potentials) required to enable excess heat as described in the Specification page 5, line 23, to page 7, line 3. Had they produced small amounts of low density excess heat, it would not have been noticed without sophisticated heat detecting equipment. Fleischmann and Pons qualitatively noted a

suspicious effect in the late 1980's, and it took several years to identify it as not being one of the well known heating effects, and to measure it. It has taken even longer to reliably replicate the effect and quantify it.

Quoting p. 8, beginning line 12:

> **"Additionally, artisans such as Price et al actually attemped to obtain nuclear fusion by subjecting deuterated Tl and Pd to temperature and/or pressure cycling (e.g. note the first column on page 1926 of Price et al) all with negative results.**
>
> **"In contradistinction, applicant alleges that in systems of that type, the deuterium instead, undergoes nuclear fusion reactions and thus said systems can be utilized for power generation due to the heat generated from the nuclear fusion reactions.**
>
> **"Assuming for the sake of argument that applicants invention does actually function in a different manner to produce a different result from that of any of Klatt et al (I), Schirber et al, or McMullen et al, it can only be because applicants invention actually contains some additional critical feature(s), component(s), etc., not found in any of said referenced which is necessary to enable applicants invention to function differently from any of said references so as to be able to produce a different result.**
>
> **"Accordingly, the disclosure is insufficient in failing to disclose said additional critical features, components, etc., necessary to cause applicants invention to operatively function in a different manner to produce a result different from that of said references."**

Remark 26a:

The following is in response to the last of the Examiner's comments above about critical features:

A description of how the reactor works is on page 9 of the revised Specification. The range of operating conditions in terms of the high operating deuterium chemical potentials, high temperatures and moderate deuterium gas pressures are shown in Figure 7 of the revised Specification. Based on that description, the range of operating conditions and other specific requirements in the Specification, the critical features of the invention are:

- Selection of the host material by measuring the threshold deuterium chemical potential in a special test apparatus to provide the minimum operating temperature and pressure combinations for enabling the fusion reaction. (Specification page 10 and Claim 24)
- Measuring the heat densities of the host material over a range of operating

deuterium chemical potentials above the threshold in a special test apparatus to provide operating temperature and pressure combinations for design and operation. (Specification page 12 and Claim 25)

- The scanning reactor for measuring thresholds and power densities is the special test apparatus noted above. (Specification page 11, in Figure 6 and in Claim 22.)
- Enabling the fusion reaction by providing the measured threshold deuterium chemical potential in the reactor by control of the reactor temperature and the deuterium gas pressure. (Specification page 9 and Figure 7.)
- Generating heat by providing operating deuterium chemical potentials above the threshold in an amount consistent with the measured power densities and the installed palladium host. (Specification page 9 and Claims 26 and 27.)
- A heat transfer system to maintain temperature stability at the desired output. (Specification page 15.)

Remark 26b:

The following is in response the beginning comments above.

The work by **Price et al** did not measure heat but concentrated on nuclear effects measured during the experiment. Also see **Remark 12** about the **Price** work not being expected to enable a fusion reaction.

The work of Fleischmann announced in 1989 reported excess heat and neutron emissions. The excess heat results were later confirmed, and the methodology well defended. The F&P work on neutron emission was found to be incorrect.

Most of the results reported in **Enclosures 2 & 3** show lack of consistent correlation between the heat and neutron emission. These results and those by SRI noted in **Enclosure 1**, show that for a large number of cold-fusion tests, excess heat correlates with the measured generation of helium, but not with nuclear emissions.

The evidence from the SRI tests described in **Enclosure 1** indicates that the cold fusion (or solid state fusion) produces largely helium-4, some small amounts of helium 3, and smaller amounts of tritium.

Neutron emissions are associated with the D-D production of helium-3 and the D-T production of helium-4. Since the principal reaction in solid state fusion is the D-D production of helium-4, neutron production would be very small corresponding to the two lesser reactions; this making the detection of the small number of neutrons very difficult even when a relatively large amount of excess heat is being produced.

One of the **critical features** of the present invention is that high system free energy states, corresponding to high D chemical potentials, above a measured threshold must be produced to enable and accelerate the fusion reaction. This critical feature is not present in any proir art, including that by **Klatt et al, McMullen et al, Carstens et al, and Schirber et al**. The D-chemical-potential, in turn is determined by the temperature of the host, the D gas pressure inside the reactor, and is not a function of the D/Pd concentraton. All of the work by **Price, et al, Klatt et al, McMullen et al, Carstens et al, and Schirber et al** was directed toward achieving high D/Pd concentrations for hydrogen storage; *therefore these works do not reflect on the efficacy of this present invention.*

Quoting p. 9, beginning line 8:

> **"There is no reputable evidence of record to support the assumption and speculation that the invention would actually operate as indicated and, produce the results as indicated."**

See **Remarks 4, 5, 6, 7, 8 and 26a** and the revised Specification.

Quoting p. 9, beginning line 10:

> **"It is not seen wherein the specification discloses any particular structure, etc., which is unique to applicants system and which would make applicants cold fusion system operative where the systems disclosed the above referenced "numereous teachings by skilled artisans", were not operative."**

Remark 27:

The Specification is clear on the enabling and operating methods as noted in "How the Reactor Works" on page 9. Remark 26a summarizes the critical features of the present invention; none of which are present in the teachings of the noted "skilled artisans". It is fortunate, indeed, that the"solid state" deuterium fusion phenominon is

enabled by electrolysis at chemical potentials around 15 kJ/mol. Had this not been the case, it might never have been discovered. High density heat is not possible by electrolysis, and, if it were, it would not be an economic method due to the need for the continuous application of power to achieve an excess.

Quoting p. 9, beginning line 14:

> **"It is apparent from the specification that applicants' concept or theory involving a "cold fusion" system that came about from the work of F & P, is workable or operative, only if these systems are already operative."**

Remark 28a:

The examiner's statement is based on there not being any possibility of deuterium fusion taking place in a palladium host. Please revisit **Remark 2** and **Enclosures 1, 4 & 7.**

Quoting p. 9, beginning line 17:

> **"However, as set forth above, the examiner has presented evidence showing that in such cold fusion systems, the claims of excess heat (as well as of other nuclear reaction products), are not reproducible or even obtainable. It consequently must follow that the claims of excess heat are not reproducible or even obtainable with applicants invention. While applicant may have set forth theoretical concepts, it is well known in the cold fusion field that theory and reality have a habit of not coinciding. There is no evidence to indicate applicant has so succeeded where others have failed, in arriving at an operable cold fusion system, i.e. that he has progressed his system beyond the point of an unproven theory or concept which still requires an undue amount of experimentation to enable the artisan to make and use the invention system for its indicated purpose. This view is also considered supported by the failure to set forth a full of the specific parameters of an operative embodiment which would produce the indicated heat output."**

Remark 28b:

Examiner's evidence that **excess heat is not obtainable or reproducible** is his basis for declaring the applicants' invention inoperable. This evidence is obsolete and is now replaced by evidence to the contrary. Please see the revised background of the invention on page 1 of the specification and the power density data in Figure 9. Also please revisit **Remark 2** and **Enclosure 1.**

In addition, all prior art is based on achieving high D/Pd loading ratios which is limiting all work to low temperatures and the attendent low power densities. Pursuit of high D/Pd loading ratios is not consistent with the available experimental evidence of high density heat. (See Enclosure 5.)

Applicants have set forth a clear distinction between their invention and all prior art in the Specification and as summarized in **Remark 26a.** and **Enclosure 5**. The applicant's **theoretical concepts** are correctly founded on the principles of thermodynamics, material sciences and solid state physics and, most important of all, are consistent with existing experimental data. Applicants have **progressed their system beyond the point of an unproven theory or concept** as evidenced in the revised specification and believe that the systems and methods setforth in the Specification make this invention operable and suitable to be practiced by artisans with skills in the fields indicated.

Quoting p. 10, beginning line 8:

"One cannot rely on the skill in the art for the selection of the proper quantitative values to present an operative cold fusion system, since those in the art do not know what these values would be. See Bank v. Raluland Corp., 64 U. S. P. Q93; In re Corneil et al 145 U.S.P.Q. 697."

Remark 28c:

The methods for selecting the proper qualitative values are now clear in the revised Specification. It is true that anyone wishing to practice this invention would require skill in more than one field such as high temperature pressure vessel design, heat transfer design, material sciences, laboratory safety in the handling of pressurized hydrogen, etc. The Specification is presented in brief sections so that the person practicing the invention will recognize where special skills may be needed.

No effort is made in the specification to teach applicable skills and technology that are readily available in texts and in universities. The principle exception to this general rule, is the inclusion of Technical Note TN-7.1, Reference 5, which iterates the founding free energy thermodynamic principles and derives Equation 1, page 10, that is used to carry out the methods set forth in the Specification. The technology presented in TN-7.1 is not generally practiced by electrochemists and is not easily extracted from the literature and texts. It is obvious that none of the artisans who

practiced gas loading techniques in the many experiments cited by the Examiner understood the technology presented in TN-7.1.

Another exception is the presentation of the "D-Pd TCP Equilibrium Diagram" in Figure 8. This equilibrium diagram is used in the design and control of sealed reactors as required in the Specification. It was developed by the applicants specifically for this invention from fragmentary experimental data published over a period of perhaps 100 years. The development of this comprehensive equilibrium diagram is described in TN-2.0 in Enclosure 9.

Quoting p. 10, beginning line 11:

> **"To reiterate briefly, the examiner has presented evidence, that neither the situation of excess 'heat' nor of other, nuclear reaction products, can reasonably be expected to be reproducible or even obtainable with the present invention.**
>
> **"There is no reputable evidence of record that would overcome the experimental showings in the above listed references, disproving this concept of "cold fusion".**
>
> **"Again, there is no reputable evidence to indicate applicant has so succeeded where others have failed, in arriving at an operative system that produces nuclear fusion or even "excess" heat, i.e., that he has progressed his system beyond the point of an unproven theory of concept which still requires and undue amount of experimentation to enable the artisan to make and use the invention for its intended purpose."**

Remark 28d:

Applicants have presented evidence that **excess heat and generation of helium by fusion of deuterium** is obtainable with the present invention as described in the Specification "Background of the Invention", in Reference 6 and in Figure 8 in the Drawings which depict experimental data in terms of power density. Arguments that excess heat and nuclear byproducts have not been proven to occur in the deterium-palladium system are no longer reason to declare this invention inoperable.

Applicants have reiterated the critical features found in the Specification for this invention in **Remark 26a**. *Additionally, they have shown that the numerous references cited in the Examiner's comments neither incorporated the critical features of this present invention nor anticipated this present invention. None reflect on the efficacy of this present invention.*

Also, please see **Remark 32** further on.

Quoting p. 11, beginning line 1:

"It is thus considered that the examiner (for the reasons set forth above) has set forth a reasonable and sufficient basis for challenging the adequacy of the disclosurel. The statute requires the application itself to inform, not to direct others to find out for themselves; In re Gardner et al, 166 USPQ 138, In re Scarbrough, 182 USPQ 298. Note that the disclosure must enable a person skilled in the art, to practice the invention without having to design structure not shown to be readily available in the art. In re Hirsch 131 USPQ 198."

Remark 29:

The revised specification now includes description of the reactor and systems together with the methods in sufficient detail for a person skilled in the art to practice the invention without having to design structure available in the art. Also see **Remark 28c**.

Quoting p. 11, line 7: **(Par. 4.)**

"Claims 1, 3, 4, 5, 17, 19 are rejected under 35 U.S.C. Section 112, first paragraph for the reasons set forth in the objection to the specification in section 3 above."

Please revisit **Remarks 1 thru 29**.

Quoting p. 11, beginning line 9:

"35 U.S.C. 101 reads as follows: Whoever invents or discovers any new and useful process, machine, manufacture, or composition of matter or any new and useful improvement thereof, may obtain a patent threrefore, subject to the conditions and requirements of this title."

(No remarks required.)

Quoting p. 11, beginning line 13:

"Claims 1, 3, 4, 5, 17, 19 are rejected under 35 U.S.C. 101 because the invention as disclosed is inoperative and therefore lacks utility."

Please revisit **Remarks 1 thru 29** and in the revised Specification.

Quoting p. 11, beginning line 15:

"The reasons that the invention as disclosed is [in]operative are the same as the reasons set forth in section 3 above as to why the specification is objected to and the reasons set forth in said section 3 above are accordingly incorporated herein."

(Note: The brackets[]above denote the assumed intent of the examiner.)

Please revisit **Remarks 1 thru 29**.

Quoting p. 12, beginning line 3:

"Applicant at best, has set forth what may be considered a concept or an object of scientific research. However, it has be held that such does not present a utility within the meaning of 35 U.S.C. 101. See Brenner v. Manson, 148 U.S.P.Q. 689."

(Note that remark numbers 30, and 31 are not used.)

Remark 32:

Virtually all prior art has been performed in the interest of scientific research. Most experimental work, even today, is characterized by a dogmatic pursuit of high D/Pd loading ratios at low, or moderately low, temperatures where power densities are very low and difficult to measure. The current approach by today's artisans offers little or no possibility of significant improvement due to the limitations on the electrolytic processes and the natural limit on loading ratio. None have specified an operable system that is economic and can be used in a commercial application. None of the 'gas loading' type of experiments enabled a fusion reaction because they lacked the essential critical features of this invention.

On the other hand, this invention is distinguished by its high utility due to producing high density heat at high temperatures; the two key ingredients to make applications of the invention economic and commercially viable. The Specification describes the reactor and systems with the methods necessary to implement a practical design.

Quoting p. 12, beginning line 6:

"Additionally, it is well established that where as here, the utility of the claimed invention is based upon allegations that borders on the incredible or allegations that would not be readily accepted by a substantial portion of the

scientific community, sufficient substantiating evidence of operability must be submited by applicant. Note In re Houghton,167 USPQ 687 ((CCPA 1970): In re Ferens, 163 USPQ609 (CCPA 1969); Puharich v. Brenner, 162 USPQ 136 (CADC 1969); In re Pottier, 152 USPQ 407 (CCPA 1967); In re Ruskin, 148 USPQ 221 (CCPA 1966); In re Citron 139 USPQ 516 (CCPA 1963); In re Novak, 134 USPQ 335 (CCPQ 1962)."

Remark 33:

Of the quoted references, the case concerning Ferens most closely parallels examiner's summary statement. We partially quote from the "Cumulative Digest", case 163 USPQ 609: (See the full text of the Ferens summary in **Enclosure 12**) (The underlining shown in the quoted text below was inserted by the applicant.)

"..... since purpose of patent system is to encourage attainment of previously unachievable results; however, where applicant predicates utility for claimed invention on allegations which border on the incredible in light of contemporary knowledge of the particular art ..... .

"..... evidence submitted to establish usefulness must be such as would be clear and convincing to one of ordinary skill in the particular art."

It is true that in 1989 and 1990, many of the scientific community, including many competent and sincere scientists, considered the "cold fusion" allegations as "bordering on the incredible". These were practitioners who had tried to duplicate the excess heat or nuclear effects and failed; others convinced by such negative results; still others assumed that when certain nuclear side effects produced during hot fusion were not present during "cold fusion", therefore the cold-fusion could not have occurred.

Some of this group, who have not been in touch with subsequent work in the field, have not changed their opinion.

But, referring to the quote from the Ferens case noted above, the operative phrase is "clear and convincing to anyone of ordinary skill in the particular art". This must be construed as referring to the technical community of several hundred in over 7 countries, who have been working in the field for the past 12 years, have written over 1,500 technical papers (many peer reviewed), conducted 8 international conferences, and many local conferences.

This small group of artisans have "ordinary skill in the particular art" and

consider the evidence "clear and convincing" that excess heat connected with deuterium fusion at reasonably low temperatures, is a reality. The specification in this invention will be clear to many of them.

Please revisit **Remark 32**.

Quoting p. 12, lines 13 thru 15:

"Claims 1, 3-5, 17, 19 are rejected under U.S.C. 112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which applicant regards as the invention."

Please see revised claims starting on page 21 of the revised Specification.

Quoting p. 12, line 16:

"Claim 1 improperly ends in a semi-colon rather that a period."

Please see revised claims starting on page 21 of the revised Specification.

Quoting p. 12, beginning line 16:

"As indicated in section 3 above, the examiner has cited several documents, e.g.. Schirber et al, Carstens et al, Klatt et al (I) and McMullen et al, which disclose systems which are considered identical to that which is disclosed and claimed by applicant and said systems are operated on in the same manner as applicants invention and that accordingly said systems in said "several documents" must inherently function in the same manner to produce the same result as that of applicant.

"Assuming for the sake of argument that applicants invention does actually function in a different manner to produce a different result from that of any of said "several documents" it can only be because applicants invention actually contains some additional, critical feature(s), component(s), etc., not found in any of said "several documents" which is necessary to enable applicants invention to function differently from any of said "several documents" which is necessary to enable applicants invention to function differently from any of said "several documents" so as to be able to produce a different result.

"Accordingly applicants claims are incomplete (as well as vague and indefinite) in failing to recite said additional critical feature(s), component(s), etc."

Remark 34:

The "several documents" cited did not employ critical features included in this invention. The critical features are clear in the Specification and are summarized in **Remark 26a.**

Also, please see the revised claims presented in the Specification starting on page 21.

Quoting p. 14, lines 8 thru 14:

> **"The applicant currently names joint inventors. In considering patentability of the claims under 35 U.S.C 103(a), the examiner presumes that the subject matter of the various claims was commonly owned at the time any inventions covered therein were made absent any evidence to the contrary. Applicant is advised of the obligation under 37 CFR 1.56 to point out the inventor and invention dates of each claim that was not commonly owned at the time a later invention was in order for the examiner to consider the applicability of 35 U.S.C. 103© and the potential 35 U.S.C. 102(f) or (g) prior art under 35 U.S.C.(a)."**

(Remark numbers 35 and 36 are not used.)

Remark 37:

All claims are jointly owned by the two applicants, Waisman and Summerl.

Quoting p. 14, lines 15 to 20:

> **"Claims 1, 3, 4, 19 are rejected under 35 U.S.C. 102(b) as being anticipated by any of Price, et al, Carstens et al, Schirber et al, Klatt et al (I) or McMullen et al.**
>
> **"Note that the references each disclose the same structure or system as in [is] recited in the claims and it is acted on in the same manner. Accordingly, this system of any of the references must also inherently function in the same manner to produce the same result as that of applicants claims.**

Remark 38:

The cited documents do not anticipate this invention since they did not inlude systems and methods incorporated in this invention. See **Remark 26a**.

Quoting p. 15, lines 1-3:

> **"As to limitations which are considered to be inherent in a reference, note the case law of In re Ludtke, 169 USPQ 563, IIn re Swinehart, 169 USPQ 226. In re Fitzgerald, 205 USPQ 594, In re Best et al, 195 USPQ 430, and In re Brown, 173 USPQ 685, 688."**

Remark 39:

The Fitzgerald case, 205 USPQ 594, closely parallels Examiner's comment and a portion is quoted here from the Cumulative Digest:

> ".....; Patent Office can require applicant to prove that prior art products do not necessarily or inherently possess characteristics of his claimed product; ....."

To respond to this statement, we refer to our **Remarks 40, 41, & 42** which follow.

Quoting p. 15, beginning line 4:

> **"Claims 1,3, 5, 19 are rejected under 35 U.S.C. 102(b) as being clearly anticipated by either Arata et al or Scaramuzzi et al."**

Remark 40:

Applicant's invention is entirely different from **Arata's** disclosure and is therefore not anticipated by it. In **Arata's** disclosure, the expressed principle of operation is to keep the D/Pd concentration high by keeping the pressure high and the temperature low. This is shown in the following quotation from p. 8 of the English translation, lines 3 through 5:

> "Also, the saturated deuterium concentration for the palladium powder is high as long as the presssure of the peripheral deuterium is high and the temperature is low as well."

Also, **Arata** employs temperatures, and resulting free energy states, far below those employed in applicant's invention as shown by the following quotation from page 8 of the English translation, lines 12 through 18:

> "Based on a normal pressure, if the temperature of the palladium that absorbs deuterium is raised, as shown in Fig. 11, the temperature migrates from regions A, in which deuterium is absorbed, to region B, in which deuterium is given off suddenly close to 105 C. Also if the temperature is lowered, deuterium is absorbed suddenly near 80 C, and the temperature returns to region A."

Arata's disclosure is based on electrolytic loading and suffers from the low temperature limitations of the electrolyte and the natural limit on the D/Pd loading ratio. The low free energy states possible in **Arata's** disclosure prevent the possibility of high density heat. While Arata did produce low density excess heat and nuclear byproducts, *it is clear that Arata did not anticipate this present invention.*

In the **Scaramuzzi** disclosure, the loaded system is cycled from D pressure in the range of 40 bar to 1/100 Torr, and the temperature cycled from 77 K to 300 K. As noted in **Remarks 11** thru **15** and **26b**, where others tried to replicate Scaramuzzi's results, the procedure was designed to maximize the D/Pd loading ratio and made no attempt to achieve high system free energy states. The maximum D chemical potential achieved by **Scaramuzzi** was less than 5 kJ/mol as calculated using the equation in this present Specification, page 6. line 11 and the 300K temperature and the 40 bar deuterium gas pressure: [$\mu = 0.5 \cdot 8.32 \cdot 300 \cdot \text{Ln}(40) =$ 4.6 kJ/mol]. This maximum system free energy state is far below the threshold required to enable a fusion reaction in a gas loaded system. *It is obvious that Scaramuzzi did not anticipate this present invention.*

Quoting p. 15, lines 6, 7:

"Claims 1, 3, 5, 17, 19 are rejected under 35 U.S.C. 102 (b) as being clearly anticipated by Yamamoto et al."

Remark 41:

The **Yamamoto et al** patent is for a device to store hydrogen isotopes in a metal solution. It employs two or more different absorbing materials, selected so that cycling the combination of the two, has an effect of 'pumping' the hydrogen, from the exterior to the interior. This invention states it can be used for a number of storage purposes, including with electrolytically loaded palladium producing "cold fusion", but otherwise does not disclose a 'cold-fusion' device.

One cannot tell from the **Yamamoto** disclosusre whether or not excess heat was ever actually produced in connection with electrolytically loaded deuterium for the specific material used. If excess heat had occurred during loading of the storage device, it would not have been detected in the absence of appropriate measuring sensors. Assuming that 'cold fusion' had occurred, it would have been of the very low power density characteristic of prior art electrolytic loading.

Yamamoto uses loading temperatures up to 50°C and pressures only up to that which can be supplied by a pressurized container, or "gas bomb", (Item 9, Figure 5). Even at "gas bomb" pressures of 200 atmospheres, the highest D chemical potential available would be only about 7 kJ/mol; well below the threshold for a gas loaded

system.

*It is clear that **Yamamoto** did not anticipate this present invention.*

Quoting p. 15, beginning line 8:

"Claims 1, 3, 4, 17, 19 are rejected under 35 U.S.C. 102(b) as being clearly anticipated by any of Aiello et al, Wada et al, Hasegawa et al, or Focardi et al."

Remark 42:

The tests conducted by **Aiello et al** were all nuclear side-effect tests and the system free energy state achieved by **Aiello** was extremely low and would not be expected to enable a deuterium fusion reaction.. **Aiello's** work is similar to the work of **Friedman, Price, McCracken, Badurek, Cooke, Harwell, Hadjas**, all of which failed to incorporate the critical features of this present invention and therefore none anticipated this present invention nor do they reflect on the efficacy of this present invention. As we have shown in **Remark 26b**, the type of fusion reactions characteristic of "solid state" fusion and in the applicants' invention is characterized by heat and the accompanying He formation; not by significant other nuclear side effects.

Similarly the **Wada et al** work and the **Hasegawa et al** work also deal only with nuclear side-effects and utilize electrostatic loading requiring the continuous application of electric power to maintain the deuterium loading.. It is clear that **Wada's** and **Hasegawa's** work neither anticipate this present invention nor do they reflect on its efficacy.

The **Focardi et al** tests were run with nickel metal and hydrogen gas, at pressures below one atmosphere. (Part of the discussion included deuterium, but hydrogen was used in the experiment.)

*It is clear that the **Focardi** work neither anticipates this present invention nor does it reflect on its efficacy.*

Quoting p. 15, line 10:

"The other references cited further illustrate pertinent art."

Remark 43:

Previous remarks include comments on all paragraphs in examiner's letter and all references cited. (End of Remarks)

DEUTERIUM HEAT GENERATOR **Marked up version.**

CIP-2 (CIP-1 No. 09/348,142 filed 07-02-99. Parent Application No: 08/917,147 filed 08-25-97.)

Inventors:
Joseph L Waisman, 25 Redwood Tree Lane, Irvine, California, 92612 and
Richard H. Summerl, 11051 Arroyo Ave., Santa Ana, California 92705.

Cross-References:
Disclosures filed by the inventors at the Patent & Trademark Office, Washington D.C:

1. Disclosure Document Number 381513 dated August 31, 1995.
2. Disclosure Document Number 401865 dated June 28, 1996.

~~U.S. Patents referenced:~~

~~3. U. S. Patent No. 5,607,563, Patterson, March 4, 1997.~~

Other references ~~(enclosed)~~:

4. "The Pathway to Commercial Applications", by J. L. Waisman and R. H. Summerl, the Proceedings of the Seventh International Conference on Cold Fusion, held in Vancouver, British Columbia, Canada, April 19-24, 1998, p 414.
5. Technical Note TN~~-7.0~~ 7.1 "The Thermodynamic State of a Gas/Solid System" issued by J. L. Waisman & R. H. Summerl, ~~5-16-99~~ revised 9-20-99.
6. "The Emergence of a Coherent Explanation for Anomalies Observed in D/Pd and H/Pd Systems: Evidence of $_4$He and $_3$He" by Michael McKubre, et al, ICCF-8, March 2000.

Background of the Invention

~~In a series of investigations, starting in the late 1980's, a new continuous, low-level, heat-producing reaction was identified that takes place after deuterium is introduced into palladium by electrolysis. At temperatures under 100°C, the power densities were less than about 100 watts per cubic centimeter of palladium.~~

~~Patterson and Cravens, Patent Number 5,607,563, claim an electrolytic cell which develops a low-level heat resulting from a hydrogen or deuterium reaction. In investigations at temperatures above 400°C, by Fleischmann & Pons, heat was~~

~~produced in a deuterium-palladium system, after extended electrolysis, at a rate above 1 kilowatt per cubic centimeter of palladium in an uncontrolled manner when the electrolytic process was halted by removing the electrolyte.~~

~~Scientific data, dating back to 1863, show that hydrogen will dissolve in some metals by gas pressure alone. Much of this published data describes the behavior of hydrogen and/or deuterium in palladium. These data generally present the hydrogen concentration in a metal for various combinations of temperature and pressure. A number of these data were re-plotted on a common format, by the present inventors, resulting in a comprehensive Deuterium-Palladium TCP Equilibrium Diagram useful in determining thermodynamic state and comparing experimental results. (Ref. 4 & 5)~~

In the 1980's, Fleischmann and Pons (F&P) discovered that excess heat was produced when electrolyzing heavy water using a palladium (Pd) cathode. Their 1989 announcement brought on a rash of hurried experiments by the technical community to try to replicate the effect that had become known as "cold nuclear fusion". Most such experiments failed; some for good cause. F&P sometimes had trouble replicating their own work. Nuclear physicists denounced the cold fusion effect because they believed that: (1) the same radiation products of deuterium fusion that had been experienced in 'hot fusion' should have been detected and (2) the Coulomb repulsion forces could be overcome only when temperatures in the 100,000,000°C range are produced. Cold fusion was branded as an incredible hoax and virtually all funding in the United States was halted.

Throughout the 1990's, a number of dedicated scientists in laboratories around the world continued the research. More and more were successful in producing excess heat by electrolysis and some succeeded in measuring the helium products of the reaction. The heat generation densities were low and the helium measured was very small and did not show a consistent relationship with the timing and rate of heat production. In all cases, investigators were pursuing the highest possible concentrations of deuterium in the palladium lattice as the enabling process; the highest concentrations being achieved at lower temperatures.

Some groups tried to achieve high D/Pd concentrations by gas loading but were unable to reach the ultra-high gas pressures to equal the high equivalent pressures achieved by electrolysis.

Other groups gave gas loading their best effort hoping to measure energized particle radiation from the deuterized palladium and other hydrogen absorbing

metals. Again their efforts were spent in trying to achieve very high D/Pd concentrations. Such experiments all failed for not recognizing that high temperature is a key ingredient for enabling a fusion reaction by gas loading.

More recently, four successful experiments which produced excess heat and showed the helium byproducts, that had been performed in four different laboratories, were carefully replicated at SRI, Int. (See Reference 6.) This replication work removes doubt about the reality of cold nuclear fusion which is now becoming known as 'solid state fusion'.

But for one notable exception, all of the reaction rates were very low and of little practical use. In their very early work, F&P actually produced high density heat, accidentally at first and later in controlled experiments. This was their "boil dry" work which they reported as "ignition" in the accidental case and "heat after death" in their controlled boil dry experiments where the heavy water electrolyte was allowed to boil away and the palladium cathodes became very hot for a long period of time. The data from this boil dry work is shown on a plot of power density vs temperature in *Fig. 9* to illustrate the significant effect of temperature in the production of high density heat.

It was this experimental work and other electrolytic work conducted at somewhat elevated temperatures that captured the attention of the present inventors who realized that the reaction rate was very much a function of temperature. The higher heat densities at higher temperatures could easily be correlated to thermodynamic principles but could not be correlated to higher D/Pd concentrations. High D/Pd concentrations at elevated temperatures cannot be achieved as noted on the equilibrium diagram for the deuterium-palladium system in *Fig. 8*.

The present inventors focused on the application of thermodynamic principles that would cause one to look, at an elevated system-free-energy state, for a 'change of state' of the deuterium within the confines of the metal lattice and that would enable the fusion reaction; a change that nullifies the Coulomb repulsion forces and makes a nuclear process possible. While this is a 'macro' point of view, it is now born out by very credible 'micro' theories currently being developed by solid state physicists.

The present inventors also focused on the necessary requirements for there to be commercial applications. For the cost of power production by this new method of heat generation in palladium to be competitive with heat produced using fossil fuels, it is necessary that it produce high density heat without the continuous input of power as is required by the electrolytic methods. The present invention will produce heat

densities that are suitable for commercial applications at high temperatures without the continuous use of power.

Brief Summary of the Invention

~~The invention consists of (1) a pressure vessel reactor containing a metal, such as palladium, which has a crystal lattice structure capable of hosting a deuterium heat-producing reaction, (2) a reactant gas, deuterium, and (3) a method of initiating and controlling the heat-producing reaction. The method employs means for: (1) dissolving deuterium in the host metal, (2) raising the chemical potential of the dissolved deuterium until the heat-producing reaction is enabled, (3) controlling the rate of heat production by controlling reactor temperature and the deuterium gas pressure, (4) controlling the reactor temperature and the stability of the reaction by controlling the heat transfer rate, and (5) extracting the generated heat by utilizing a suitable heat transfer system.~~

The present invention is a reactor and system with a method for containing and controlling a deuterium nuclear fusion reaction in a host metal lattice, such as palladium, now generally referred to as 'solid state fusion'. The reactor is designed for high temperature operation at moderate deuterium gas pressures and is operable over a temperature range of 400°C to more than 1400°C. Temperatures up to 3000°C are achievable for host metals with high melting temperatures.

The solid state fusion reaction is enabled and controlled by providing specific combinations of reactor temperatures and deuterium gas pressures in the host metal's surroundings. Free energy thermodynamic principles are applied to determine the specific combination of temperatures and pressures for enabling and controlling the fusion reaction. They involve providing a high system free energy state, corresponding to a high deuterium-chemical-potential, that is above the threshold for a 'change of state' of the dissolved deuterium where it can and will achieve a new lower free energy. It is this 'change of state' that nullifies the Coulomb repulsion forces and permits fusion to occur. (See the definition of chemical potential given later.)

The deuterium, D, chemical potential is controlled by controlling the D gas pressure, P, and the reactor temperature, T. **It must be remembered that for every value of D chemical potential, there is a specific associated family**

of temperature and D gas pressure combinations that will produce that same chemical potential value as is seen in *Fig. 7*. The fusion reaction is accelerated by increasing the operating D chemical potential, above the threshold.

To provide metals capable of hosting the reaction, a selection process of testing candidate host metals in a 'scanning reactor' is used to determine reaction thresholds and heat rates. The measured threshold chemical potential establishes the minimum operating conditions, temperature and pressure combinations, for the onset of heat production for a particular host metal and form. The measured heat production rates provide the temperature and pressure combinations necessary to achieve a desired heat production rate.

A means for stabalizing the temperature of the reaction by controlling the heat transfer rate is provided in the heat transfer system.

The reactor may be permanently sealed after 'loading' the deuterium, allowing the reactor to be stored and then operated separate from its deuterium pressurizing equipment. Use on a moving vehicle that requires portability of its energy source would be a typical candidate application for the sealed reactor. An inert filler material in the void space of the sealed reactor may be used to reduce the gas volume inside the reactor thereby amplifying the pressure increase achieved with increasing temperatures. For the amplification to be large, the void space volume must be reduced to be on the same order as that of the palladium. The life of a sealed reactor is limited due to the depletion of deuterium as helium is formed.

The heat-producing reaction is self-sustaining once ~~started~~ enabled.

Brief Description of the Drawings

~~Figures 1 and 2 show longitudinal and transverse cross-section views, respectively, of a typical reactor indicating the arrangement of the host metal on the inside and of the heat transfer surfaces on the outside.~~

Fig. 1 is a longitudinal cross-section of a typical reactor showing the general arrangement of the host metal inside of the pressure vessel and the enabling heater (coil) on the outside surrounded by the heat transfer surface. The configuration shown in *Fig. 1* is typical for heat transfer by radiation where the outer surface has a high emissivity. The enabling heater may be integrated into the heat transfer system if desired, rather than in the heat transfer surface, as is illustrated in *Fig. 4* and in the

schematic in *Fig. 5.* ~~They~~ Fig 1 also shows the location of the permanent seal when used, the inert filler material when used, and the thermocouple when used.

Fig. 2 shows the same typical reactor except with fins integrated into the heat transfer surface for heat transfer by convection.

Fig. 3 is a transverse cross-section of the reactor.

Fig. 4 is an alternate arrangement where the host metal is located in a position other than on the inside surface of the outer wall of the pressure vessel. Here the enabling heat is provided by externally heating the heat transfer fluid during start-up.

Figure ~~3~~ 5 is a typical schematic of the reactor and its operating system ~~for heat generation~~ when the heat transfer method is by forced convection. ~~Included are deuterium loading, heat transfer and stability control.~~ Alternate control systems may be employed to suit the application requirements.

Fig. 6 shows a general arrangement of the scanning reactor, the temperature probe and a typical test sample.

Fig. 7 is a plot of the 'System Free Energy State' versus 'Operating Temperature' showing the range of operating chemical potentials, and the associated temperatures and pressures, over which the present invention is operable. An extended range is also noted.

Fig. 8 is the Deuterium-Palladium TCP Equilibrium Diagram.

Fig. 9 is a plot of selected experimental data showing where high density heat was produced at high temperatures.

Detailed Description of the Invention.

The reactor assembly:

Referring to the *Fig's. 1 and 2*, the deuterium heat generator 1, is hereafter called the 'reactor' or the 'reactor assembly'. The reactor assembly 1 consists of: the pressure vessel 2; the host metal 3; the enabling heater 34; the heat transfer surfaces 4; a high pressure gas connector 5 to facilitate connection to the high pressure manifold 13; a permanent sealing device 6 when used; an inert filler material 7 when used; and a temperature transducer 8 when used to determine the approximate host metal temperature. The heat transfer surfaces 4: may be plain; may have fins for heat transfer by convection; or may have a high emissivity coating for heat transfer by

radiation. Heat transfer by a combination of convection and radiation may also be employed when that best suits the requirements of the application.

The reactor assembly 40 in *Fig. 4* illustrates how the host metal 3 may be located in an alternate location in the pressure vessel. In this instance, the control schematic (not shown) would embody the same principles that are embodied in the schematic shown in *Fig. 5*.

When the reactor is to be permanently sealed, the opening to the reactor assembly must include a suitable device 6 and method for sealing at its predetermined 'loading' temperature and pressure. Such a device is one that provides a slightly tapered hole in a thick walled, restricted section of the filler neck that is transverse to the gas filling path and intersects it. An extrudable material is held in the transverse tapered section to provide the 'working' seal. When the permanent seal is to be made, the transversely held material is extruded into the filling path using a side force. Both the side and end openings may then be electron beam welded to form the long term permanent seal. Once the reactor is sealed, it must be stored at a suitable temperature that is well below the threshold temperature to ensure that the fusion reaction is not accidentally enabled. (See the later section on How the reactor works.)

The reactor body:

In the preferred embodiment, the reactor pressure vessel body is made from a suitable high-strength, high-temperature metal or alloy which has one or more of the following properties: (1) impervious to hydrogen, (2) is not subject to hydrogen embrittlement and/or (3) is coated on the inside with a material such as beryllium-bronze which is impervious to hydrogen and its isotopes. The optimum diameter of the reactor pressure vessel and the thickness of the material used to form the pressure vessel body are determined by stress and strength analysis to suit the operating conditions.

Generally, it is the application requirements that will set the design operating temperature; the materials and dimensions for the reactor body must be appropriately selected. In *Fig. 7*, the operable temperature range is from 400°C to more than 1400°C.

In the lower to mid-range operating temperatures of 400°C to 1000°C,

materials for the pressure vessel body may be selected from a group of alloys used in the manufacture of jet engine turbine blades and in other high temperature uses. ~~Other materials may suit reactor conditions which are less demanding.~~ One such material is Carpenter's Pyromet Alloy 680 which is ideal for the 400°C to 1000°C range and is inexpensive and easy to machine.

For the higher temperatures in the 1000°C to 1400°C range, a material such as pure tungsten may be used. The operating range shown in *Fig. 7* is applicable when the host metal is a metal such as palladium with a melting temperature in the 1500°C range.

When using tungsten for the reactor body, the operating range of temperatures noted in *Fig. 7* may be extended up to 3000°C for use with a host metal having a high melting temperature. Also, when using tungsten for the reactor body, the range of operating deuterium chemical potentials may be extended into the 60kJ/mol range.

The host metal:

In the preferred embodiment, palladium is the host metal. Other candidate host metals may be selected from a group consisting of: titanium, zirconium, vanadium, thorium, lanthanum, praseodymium, tantalum, uranium, halfnium, nickel and cerium. The host material may also be an alloy, or mixture, of the selected metal with one or more other elements. ~~Suitable~~ Candidate host metal forms include wire, plate, foil, powdered and deposited forms. **[Paragraphs** *"The design thickness of the host metal will vary from a fraction of a millimeter to several millimeters depending upon the host material selected and the required surface power density. The length, or overall size of the reactor is a function of the total power required."* **and** *"In the preferred embodiment, the host metal is affixed to the inside surface of the reactor so that heat flow from the host metal to the heat transfer surfaces is enhanced. Other designs may place the host metal at other locations inside the reactor. Candidate processes for installation of the host metal include: various deposition processes and other solid forms, which may be on a sub-strait and otherwise fixed in place, and powdered forms sintered in place or otherwise confined. The host metal is cleaned after installation to remove surface contamination and facilitate the dissolution of deuterium."* **have been moved to later section: "Host Metal Installation". The final selection of the host metals is described in a later section, Host Metal Selection.]**

The reactant gas:

In the preferred embodiment, the reactant gas is deuterium, D_2. ~~Some small amount of other gasses or other materials may also be mixed with the deuterium reactant gas.~~

How the reactor works:

The objective of the method described in this section is to enable and accelerate the heat producing reaction for the purpose of producing high density heat. Following this method will create and exceed the system free energy states indicated in the experimental evidence presented in *Fig. 9.*

~~The~~ Presurized deuterium is dissolved in the host metal by ~~confining the deuterium gas~~ virtue of its being in contact with the surface of the host metal. ~~The amount of deuterium that dissolves per unit of host material is a function of (1) the temperature of the host metal and (2) the pressure of the deuterium gas.~~ The concentration of deuterium in the host metal is given by the ~~temperature, concentration and pressure,~~ D-Pd TCP Equilibrium Diagram ~~for the gas-metal system~~ as shown in *Fig. 8.*

At the high temperatures where the system is operative and high density heat is being produced, *Fig. 9,* the D/Pd concentrations will be low as indicated on the Equilibrium Diagram. There is no finite minimum D/Pd concentration required for operation; only that some deuterium be present.

The heat producing reaction is enabled by raising the ~~thermodynamic~~ system free energy state, corresponding to the deuterium gas chemical potential, ~~of the gas-metal system~~ to its ~~critical~~ reactive threshold level, ~~where~~ At the threshold level, the 'dissolved' deuterium undergoes a change of state, seeking its lowest possible free energy. It is this change of state that nullifies the Coulomb repulsion forces and enables the fusion reaction. The chemical potential of the 'dissolved' deuterium, at equilibrium, is uniform throughout the host metal and it is a function of the deuterium 'gas' chemical potential at the surface of the host metal. The 'gas' chemical potential can be measured and controlled by controlling the D gas pressure and the reactor temperature. The threshold of the heat producing reaction is the deuterium 'gas' chemical potential that produces the ~~critical~~ 'dissolved' deuterium chemical potential

that is critical to its change of state. The relationship between the gas chemical potential and the chemical potential of the dissolved deuterium is explained in Technical Note TN-7.1, Reference 5, and is shown explicitly in equations (h), (i) and (j) of that document. The heat-producing reaction is spontaneous once it is enabled. The rate of the heat production is increased as the operating chemical potential is raised above the threshold.

For the sealed reactor, only the temperature can be controlled directly and the pressure for any given temperature is a function of that temperature. The pressure and the associated D chemical potential may be predicted for any given temperature knowing the ratio of the 'free-gas-volume' to the 'palladium volume' installed in the reactor as described in the later section, Predicting the performance of sealed reactors.

Chemical potential:

In the present invention, the term 'D chemical potential' is used as a measure of the free energy state of the system. The term 'chemical potential', when used for a gas-metal system, is defined as the change in Gibbs Free Energy, in Joules per mol, that would be required to force one more mol of a gas into a large gas/metal system, at its present free energy state, while holding the temperature, pressure and the concentration of other species constant. The chemical potential, μ, of the deuterium gas is given by the equation:

$$\mu=(0.5R\mathbf{T})\mathrm{Log}_n(\mathbf{P}/P_0) \qquad \text{(Equation 1)}$$

where: μ is the gas chemical potential (J/mol), R is the gas constant (8.32 Joules/mol°K), T is the temperature in Kelvin, P is the deuterium gas pressure in atmospheres and P_0 is the selected standard state pressure of 1 atmosphere. Since the chemical potential of the dissolved deuterium is a function of the gas chemical potential, it also is a function of the two control variables, **T** and **P**.

Host metal selection:

The threshold deuterium gas chemical potential may ~~be different for each candidate host material~~ vary from one candidate host material lot to another. The

threshold chemical potential ~~of the~~ for a specific host material is also dependent on the system's electronic Fermi energy as well as other factors including the purity, crystal size and regularity, and the population of flaws, cracks, vacancies, distortions and dislocations in the crystal lattice structure of a particular host material. Some of these micro-properties might be altered in the process of installing the host inside of the reactor.

Because of this variation in micro-properties, each lot of the candidate metals is subjected to screening tests, in their final form, to determine their threshold deuterium gas chemical potentials. Such screening tests and measurement of the threshold chemical potential are conducted for any candidate host metal ~~in a The threshold deuterium gas chemical potential may be measured for any candidate host material~~ in a properly instrumented pressure vessel. The material-form combinations with the lowest threshold chemical potentials are the best candidates. The final selection of a metal and form will be dictated by the application requirements.

The 'instrumented' pressure vessel for screening the candidate host materials is called a 'scanning' reactor with means for temperature and deuterium gas pressure control. For the scanning reactor to be an effective tool for the process of selecting the host metal and form, it is designed for a broad operating range in terms of high D chemical potentials, high temperatures and high pressures. When the reactor body is made from pure tungsten, D chemical potentials up to the range of70 kJ/mol, operating temperatures up to about 3000°C and D gas pressures up to the range of 4000 atmospheres can be achieved.

A typical general arrangement of the scanning reactor and typical test samples are shown in *Fig. 6.*

- The scanning reactor body 41 is designed to minimize heat conduction to its attachment base and to minimize heat radiation to its surroundings. By operating in the vacuum provided by the vacuum chamber 44, the losses by convection are eliminated. The sensitivity of threshold measurements and the accuracy of heat rate measurements depend on how well the reactor is isolated. The material for fabrication of the reactor body 41 should be selected from the group of candidates for the production reactor noted in the previous section, The reactor body.
- The heater coil 42 is the means to control the temperature of the test sample.
- The base of the vacuum chamber 44 incorporates the D_2 gas pipe

connections 46 for the scanning reactor and the external piping. The base also incorporates the electric wire feed-thru 45 and the vacuum port 48.

- The cross fitting 47 permits ready through access to the reactor body for the test sample assembly 55 facilitating rapid change of test samples with just a single high pressure disconnect. It 47 also provides side ports for the high pressure D_2 gas from the gas supply system 51 and access to the vacuum system 52. The D_2 gas pressure gage 50 provides the necessary pressure data for calculating chemical potentials.
- The test sample assembly 55 consists of a substrate 56 and the host metal sample 57. The host metal sample 57 is processed onto the substrate using the installation process planned for the production reactor.
- The thermocouple 43 is the reference measurement for detection of the onset of fusion heating by the thermocouple 54 on the temperature probe 53. When the system is at thermal equilibrium and the fusion reaction is not yet enabled, the two thermocouples 43 and 54 will read alike. When the onset of the fusion reaction is reached, the thermocouple 54 on the probe will read higher than than the thermocouple 43 on the reactor body. The temperature rise (54 minus 43) due to the onset of 'fusion' heating is one that persists beyond the transient heats due to dissociation, ionization, solution and lattice transformation.

Measurement of the threshold D chemical potential is accomplished by recording the reactor body temperature 43 and gas pressure 50 at the onset of the heat producing reaction when a temperature rise 53 of the test sample above the surroundings is detected. The threshold chemical potential is then calculated from the Equation 1 noted above using that temperature 43 and pressure 50 recorded at the onset.

Once the threshold D chemical potential is measured for particular sample, there is a family of temperature and pressure combinations that will produce that same D chemical potential that now may be used in design as the minimum operating conditions to enable the fusion reaction.

The scanning reactor is also used to measure the heat production rates over the range of operating temperatures specified for the application. For the scanning reactor to be effective for measuring rates, it must also incorporate calorimetry. One direct measurement method is by noting the reduction of control heater 42 power to

maintain constant temperature 43 when the test sample 57 is producing heat. For this method of calorimetry, all heat losses must be minimized. To make these rate measurements, the installed volume of the host metal sample 57 is adjusted so that the heat generated at the test operating conditions is approximately equal to the mid-range of heat produced by the heater 42. Knowing the heat necessary to make up the losses in the system at the test temperature, the heater power may be reduced from its 'loss maintenance' rate to compensate for the heat generated by the test sample, thereby maintaining a constant temperature and giving a direct reading of the heat generated.

Knowing the volume or weight of host metal in the test sample, the average power density may be readily calculated, in watts per cubic centimeter, for each level of operating chemical potential applied. It is this heat production rate characteristic of the host metal that will permit determination of the thickness of the host metal to be used for a particular application.

The scanning reactor is also used to determine the slope of the heat generation rate curve at the design operating temperature so that the heat transfer system may be designed for stability. The slope of the heat transfer characteristic curve at the operating conditions must be greater than the slope of the power production curve at that point for there to be a stable operating temperature. Determining the slope of the sample's characteristic heat production curve is accomplished by measuring the heat generation rate over a range of temperatures above and below the design operating temperature and plotting the data for analysis.

Host metal installation:

In the preferred embodiment, the host metal is affixed to the inside surface of the reactor so that heat flow from the host metal to the heat transfer surfaces is enhanced. Other designs may place the host metal at other locations inside the reactor. This is illustrated in Figure 4 where the heat transfer surface is along the central heat transfer fluid tube 36. ~~Candidate processes for installation of the host metal include: various deposition processes and other solid forms, which may be on a sub-strait and otherwise fixed in place, and powdered forms sintered in place or otherwise confined.~~

Candidate methods for installation of the host metal include: (1) various

deposition processes, (2) other solid forms, which may be on a substrate, and (3) powdered forms sintered in place, or otherwise confined. Some candidate methods of installing the host metal are briefly described here:

(1) Fabricate the host metal in the form of a tube in the metal-producing mill by standard techniques of casting, and a series of "drawing" steps with intermediate anneals. This is a "bulk" technique. The dimensions of the host metal tube are such that the outside is a close fit to the inside of the reactor body. The outside surface of the host metal tube may be coated with brazing material. After insertion, a mandril may be inserted to expand the host tube to an "interference" fit. The assembly is then heated to the brazing temperature to produce a strong and conductive interface.

(2) Another method employs the use of host metal in a powdered form, available commercially, which is placed into position so the powder tightly fills a tubular space inside the pressure vessel, kept in place by a mandril. The assembly is then heated to the sintering temperature, which produces inter-diffusion of host metal powder particles so they become firmly attached to each other and to the inside surface of the reactor body. The mandrel is then removed.

(3) Still another method is to use a vapor-deposition technique in which a vapor of host metal is produced in an evacuated space and is deposited in a layer on the inside surface of the reactor body.

The host metal is cleaned after installation to remove surface contamination and facilitate the ~~dis~~solution of deuterium.

The design thickness of the host metal will vary from a fraction of a millimeter to several millimeters depending upon the host material selected, its measured heat production rates over the operating temperature range and the required surface power density, or heat flux, specified for the application. ~~The length, or overall size of the reactor is a function of the total power required.~~

The present invention is operable with any one of many installation methods. In each case, the threshold D chemical potential and the power production characteristics are determined by 'scanning' tests for the specific combination of host metal and installation process to complete the design.

System control.

Heat production rate stability is preserved by maintaining a constant host metal temperature for a given deuterium gas pressure. This is accomplished by ensuring that the heat transfer rate away from the reactor is equal to the heat generation rate. Since the reaction heat rate is an exponential function of temperature, positive temperature feedback and 'run-away' may occur if the heat transfer rate is inadequate.

When heat transfer is by forced convection, the host temperature, for a given deuterium gas pressure, is controlled by controlling the temperature and the flow rate of the heat transfer fluid as seen in *Fig. 5.*

When heat transfer is by radiation, with a high operating temperature for the reactor and a low receiver temperature, the heat transfer rate is essentially a fourth power function of absolute temperature of the reactor. In general, if the reactor heat generating rate, being an exponential function of temperature, is less than a fourth power function of temperature, then the reactor will be stable at the design operating temperature. If the heat generation rate is greater than a fourth power function of absolute temperature, then supplemental convection cooling of the reactor may be required to maintain stability.

Control of the sealed reactor.

Startup and control of the sealed reactor is accomplished by controlling only the temperature of the reactor.

The performance of a sealed reactor is determined the same way as that for a pressure controlled reactor; the fusion reaction is enabled by producing the threshold chemical potential measured for the host metal in the scanning reactor. The rate of the reaction is increased by increasing the operating D chemical potential over the threshold. The difference for the sealed reactor is that the internal D gas pressure cannot be changed independently or even measured easily. It can, however, be predicted and the D chemical potentials can then be calculated for any given temperature.

By predicting the internal pressures and calculating D chemical potentials over the operating temperature range, the threshold temperature and the heat generation

rates of the reactor at various temperatures above the threshold can be calculated.

Predicting the performance of sealed reactors:

When the reactor is operating in the sealed condition, the internal reactor pressure, at any given temperature and gas volume, is dependent on (1) the mass of the deuterium in the host metal and in the void volume at the time of sealing, and (2) the ratio of the 'void-volume' to the 'host-metal-volume' inside the reactor. The pressure is controlled by controlling the reactor temperature.

To predict the pressure for any given temperature, it is necessary to first determine the total number of mols of deuterium that were 'installed' at the time of sealing. To determine the number of mols of deuterium in the host metal, the total number of mols of host metal installed inside the reactor must be known and the reactor temperature and gas pressure at the time of sealing must have been measured. The number of mols of dissolved deuterium within the host metal is then determined using concentration data from the TCP Equilibrium Diagram. The number of mols of deuterium in the void volume, n, is calculated using the ideal gas law, PV=nRT. The sum of the two numbers will remain the same once the reactor is sealed, but, as temperature is increased, some of the dissolved deuterium in the metal will be driven into the void volume thereby amplifying the pressure increase that would have occurred had there been no change in the concentration of deuterium in the host metal. At the higher temperature, a new equilibrium will be reached at a higher pressure in the void volume and, in turn, will further increase the operating chemical potential. The amplification factor is a function of the ratio of 'void-volume' to 'host-metal-volume'. This ratio may be adjusted in design by adding an inert filler material to the void space.

When the void volume is large relative to the host-metal volume, the pressure amplification due to deuterium expulsion from the host metal with a rise in temperature is small. When an inert filler material is used to significantly reduce the void volume, the pressure amplification as a result of deuterium expulsion from the host metal may be made very large (in the range of 100 times and more) depending on how much the void volume is reduced by the filler. The preferred material for the inert filler material is one which is relatively impervious to hydrogen. The filler material may be a solid core or a closely packed loose material. Quartz or alumina ~~is~~

are ~~a~~ candidates for the filler material.

Useful life of the sealed reactor:

The useful life of the reactor 1, when operating sealed, is limited since deuterium is depleted in the reaction. As deuterium is converted to helium, the partial pressure of the deuterium in the void space will decrease and the partial pressure of the helium will increase. This decrease in the partial pressure of the deuterium will have the effect of reducing the operating D chemical potential and hence the rate of the fusion reaction. When the application requires that the heat generation rate remain constant, then it will be necessary to compensate for the drop in pressure by operating the reactor at a correspondingly higher temperature to maintain the same operating D chemical potential. In convective heat transfer, this is accomplished by decreasing the heat transfer rate. This action will cause the temperature to rise and the correct operating D chemical potential to be restored. When the operating heat generation rate is restored at a higher temperature, then the heat transfer rate may require readjustment so that it is equal to the restored heat production rate.

In this case, the useful life of the sealed reactor is limited to how much adjustment in operating temperature can be made before the maximum temperature allowable for that particular reactor body design and material is reached.

When the application can tolerate a drop in the heat generation rate, then the useful life of the sealed reactor is limited to the time to reach the minimum heat generation rate that meets the minimum application requirements.

The Operating System:

A given reactor operating system is designed to fit the application requirements in terms of the operating conditions and the method of heat transfer. As a minimum, the control system must incorporate: (1) a means to load the deuterium into the reactor and host metal, (2) a means of controlling the chemical potential of the dissolved deuterium, (3) a means of extracting all of the generated heat and thereby providing a means of controlling the temperature of the host metal.

Loading the Reactor:

Referring to *Fig. 3*, the deuterium gas pressurization system consists of a gas storage system 9, pressurization pumps 10, vacuum pumps 11, isolation valves 12, a high pressure manifold 13 to interconnect the components and to connect the system to the reactor assembly 1. The pressure in the manifold is indicated by pressure gage 14 which may include an electronic pressure signal to the operating control panel 27. The gas storage system 9 may include filters, traps, regulators, etc.

The reactor 1, the manifold 13, the pressurizing equipment 10, the gas storage equipment 9 and associated lines are evacuated through the isolation valves 12 using the vacuum pumps 11 to remove contaminating gases. When the enabling heater 34 (in *Fig. 1 & 2*) is not integrated into the heat transfer surfaces, then the operating chamber 15 heater 17 may be operated to raise the temperature of the reactor to a value in the 600 to 800°C range for an extended period of time while under vacuum to remove residual contamination from the reactor and host metal.

Typical loading procedures:

In the preferred loading method, the temperature of the reactor 1 and the operating chamber 15 is raised above ~~300~~ 400°C while still under vacuum using the enabling heater 34 (*Fig. 1 & 2*) or heater 17 (*Fig. 5*). The heat transfer fluid pump 20 is off during the loading procedure. The isolation valves 12 are closed and the deuterium gas supply valve and regulator 9 are opened. The deuterium gas is pumped into the high pressure manifold 13 and reactor 1 using the pressurization equipment 10 controlled from the control panel 27 and is indicated on the manifold pressure gage 14. The gas pressure is raised to that value necessary, at the loading temperature 8, to achieve the threshold chemical potential for heat generation. At this operating point , the reactor 1 is ready for operation as a heat generator. When the threshold chemical potential cannot be reached at the selected loading temperature, then a higher loading temperature must be used. An alternative is to load at the lower temperature and then raise the temperature until the threshold is reached.

When the reactor is to be used as a sealed reactor, it is loaded with deuterium to a predetermined temperature and pressure and then sealed. The final loading temperature and pressure at sealing are selected so that the deuterium gas pressure inside the reactor will reach the correct pressure at the design operating temperature

to produce the required chemical potential which, in turn, produces the desired heat generating rate.

After permanently sealing, ~~the~~ a reactor, may be removed from the pressurization system and stored for later use as a heat generator. Controlled low temperature storage may be required to ensure that the threshold chemical potential is not accidentally reached.

System operation:

Referring to *Fig. ~~3~~ 5* the operating chamber 15 consists of: insulation 16 on the outside, a heater 17 on the inside (or other means of heating the reactor for start-up), a heat transfer fluid distribution system 18 which ensures that virtually all of the fluid impinges on the reactor's heat transfer surfaces, an inlet temperature thermocouple 28 for control of the fluid temperature as it begins circulation over the reactor surfaces. A calorimetry system 30 utilizes inlet and outlet thermocouples 32 & 33 and the heat transfer fluid mass flow meter 31 to determine the heat generation rate.

The heat transfer system utilizes a heat transfer fluid, circulating in lines 19, 23 and 25, which may be a gas or a liquid to suit the application, and consists of: the circulation pump 20, mixing valve 22 for controlling the temperature of the heat transfer fluid 28 at the inlet of the operating chamber 15, the cooling heat exchanger 24 and cooling line 25 which supplies cooler fluid to the mixing valve 22, a heating by-pass line 23 which provides hotter fluid to the mixing valve 22, flow rate control valve 26 to provide heat production stability control by ensuring that the heat transferred out is equal to the heat generated in the reactor, and the mass flow meter 31 which provides data required for calorimetry 30. The loads 21 and heat rejection devices 24 remove the generated heat. The flow rate control valve 26 may be eliminated if the pump 20 has a flow-rate control feature built into the pump.

Before operating the system, the operating chamber 15 and all of the heat transfer fluid components, including the heat-using devices 21, are purged of all unwanted fluids and the selected heat transfer fluid with a known specific heat is introduced.

Typical Operation at the Desired Power Production Rate

Once (1) the reactor 1 and the heat transfer system have been brought up to the design operating temperature range 8, (2) the deuterium gas pressure 14 has been increased so that the threshold of heat production has been surpassed and (3) the reactor heat generation rate exceeds the system loss rate, the heater 17 (or the enabling heater 34) may be turned off. The host metal temperature is now under control of the heat transfer system. It is controlled by adjusting (1) the mixing valve 22 position to provide heating 23 or cooling 24 & 25 of the heat transfer fluid after heat is extracted by the loads, and (2) the heat transfer fluid flow rate control valve 26.

The average power production rate is controlled by controlling the reactor temperature 8, as noted, and the deuterium gas pressure 14 so that load demands 21 are met with the mixing valve 22 in approximately the center position. Short-term changes in load demand are met by adjustments in the heat transfer fluid temperature 28 and flow rate 26. Reactor stability control takes priority over load demand.

When the reactor is operating sealed, the power production rate is modulated by adjusting the operating temperature 8. As the deuterium is depleted, the power production rate for a given temperature will decrease. To compensate, the reactor is operated at gradually higher temperatures over the life of the reactor. This is accomplished by adjusting the flow rate control vale 26. A reduced flow will increase the operating temperature and an increased flow will reduce the operating temperature. After any adjustments in temperature, it is necessary to restore the heat transfer rate to be equal to the generation rate for stability.

With the reactor is operating unsealed, it, and its operating system, will require periodic maintenance to remove the product of the reaction, helium. When the reactor is operating sealed, it will require periodic recycling to remove the product of the reaction.

~~What is claimed is:~~ We Claim:

~~1. A system for generating heat from deuterium comprising:~~

~~• a pressure vessel reactor; said reactor having a void space;~~

~~• a host metal, said host metal distributed inside said reactor;~~

~~• a reactant gas, deuterium, within said reactor void space and dissolved in said host metal; said heat generation from the dissolved deuterium dependent on the deuterium gas pressure and the reactor temperature;~~

~~• means of controlling said reactor temperature and said deuterium gas pressure;~~

~~• means of controlling said reactor temperature by controlling the rate of heat extraction;~~

1. A system for generating solid state deuterium fusion heat at elevated system free energy states, corresponding to high deuterium chemical potentials, comprising:

• a pressure vessel reactor; said reactor having a void space; said void space containing a host metal and deuterium gas; said deuterium gas at elevated pressure within said reactor void space and dissolved in said host metal;

• a means of providing a vacuum in said reactor before said deuterium is introduced;

• means of controlling said reactor's temperature and said deuterium gas pressure;

• means of transferring the generated heat to a useful load.

~~2. A system as set forth in claim 1, wherein said host metal inside said reactor is one taken from the group consisting of: palladium, titanium, zirconium, vanadium, thorium, lanthanum, praseodymium, tantalum, uranium, halfnium, nickel and cerium.~~

~~3. A system as set forth in claim 1, also comprising a means of sealing said pressure vessel after introducing said deuterium; said deuterium gas pressure, after sealing, being dependent upon the reactor temperature;~~

3. The system of in claim 1, comprising:

• a means of permanently sealing said pressure vessel after introducing said deuterium.

~~4. A system as set forth in claim 3, also comprising inert filler material inside said pressure vessel to reduce the void space; said reduction in void space causing an~~

~~amplification of said deuterium gas pressure increase when said reactor temperature is increased.~~

4. The system of claim 3, comprising:
    - inert filler material inside said pressure vessel to reduce said void space; said reduction in void space enhancing the deuterium gas pressure increase as the reactor temperature is increased.

5. The system of claim 1, wherein said host metal is palladium.

6. The system of claim 1, wherein said host metal is titanium.

7. The system of claim 1, wherein said host metal is nickel.

8. The system of claim 1, wherein said host metal is zirconium.

9. The system of claim 1, wherein said host metal is vanadium.

10. The system of claim 1, wherein said host metal is thorium.

11. The system of claim 1, wherein said host metal is lanthanum.

12. The system of claim 1, wherein said host metal is praseodymium.

13. The system of claim 1, wherein said host metal is tantalum.

14. The system of claim 1, wherein said host metal is uranium.

15. The system of claim 1, wherein said host metal is hafnium.

16. The system of claim 1, wherein said host metal is cerium.

~~17. A system of claim 1, wherein said host metal inside said reactor is in a deposited form.~~

18. The system of claim 1, wherein said host metal is in a powdered form.

19. The system of claim 1, wherein said host metal is in a solid form.

20. Using the system of claim 1, comprising:
    - a method in which deuterium gas chemical potentials in the range of 15 kJ/mol to 50 kJ/mol are produced at temperatures ranging from 400°C to 1500°C and at deuterium gas pressures ranging from 25 atmospheres to 2,000 atmospheres.

21. Using the system of claim 3, comprising:
    - a method in which deuterium gas chemical potentials in the range of 15 kJ/mol to 50 kJ/mol are produced at temperatures ranging from 400°C to 1500°C and at deuterium gas pressures ranging from 25 atmospheres to 2,000 atmospheres.

22. A system for testing candidate host metals to determine their threshold deuterium gas chemical potentials and heat production rates comprising:

- a pressure vessel reactor; said reactor for containing said candidate host metal and deuterium gas under pressure;
- a heater surrounding said reactor;
- a means of providing a vacuum in said reactor before said deuterium is introduced;
- a system design that minimizes heat transfer away from said candidate host metal and heat transfer away from said reactor;
- a probe for supporting said host metal in said reactor;
- a temperature sensor in the end of said probe;
- means of measuring said deuterium gas pressure and said reactor temperature;
- means of controlling said reactor temperature and said deuterium gas pressure;
- a means of measuring the heat generation rate within said host metal.

23. Using the system of claim 22, comprising:
- a method in which said deuterium gas chemical potentials in the range of 15kJ/mol to 75kJ/mol are produced at temperatures ranging from 400°C to 3000°C and at deuterium gas pressures ranging from 5 atmospheres to 4000 atmospheres.

24. Using the system of claim 22, comprising:
- a method in which the said threshold deuterium gas chemical potential at the onset of heat generation is determined for said candidate host metal.

25. Using the system of claim 22, comprising:
- a method in which said heat generation rates are determined for said candidate host metal.

26. Using the system of claim 1, comprising:
- a method of said heat generation by providing said deuterium chemical potentials in excess of measured threshold deuterium chemical potentials for said host metal.

27. Using the system of claim 3, comprising:
- a method of said heat generation by providing said deuterium chemical potentials in excess of measured threshold deuterium chemical potentials for said host metal.

Abstract

~~The deuterium heat generator is a pressure vessel reactor containing deuterium gas and a metal, such as palladium, having a crystal lattice structure capable of hosting a deuterium heat-producing reaction. The deuterium is dissolved in the host metal and its chemical potential is raised until the heat-producing reaction is enabled. The controls for the reaction are (1) the deuterium gas pressure and (2) the reactor temperature. The reactor temperature and the stability of the reaction is controlled by controlling the heat extraction rate. When the reactor is sealed after loading deuterium, it may be stored and then operated separate from its pressurizing equipment. The heat-producing reaction is self-sustaining, once started.~~

This invention is a reactor and system with a method for containing and controlling a deuterium nuclear fusion reaction in a palladium host metal lattice, now generally referred to as 'solid state fusion'. The reactor is designed for high temperature operation at moderate deuterium gas pressures and is operable over a temperature range of 400°C to more than 1400°C. The solid state fusion reaction is enabled and controlled by providing specific combinations of reactor temperatures and deuterium gas pressures. The invention is capable of generating heat densities that are suitable for commercial applications. The highest heat densities are produced at higher temperatures and moderate pressures where the system is most efficient and cost effective.